Characterization of Slip System Activity and Deformation Behaviour in P91 Steel by Micropillar Compression Testing and Crystal Plasticity Simulation

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Abstract

This study investigates the slip system activity and deformation mechanisms of P91 martensitic steel at room temperature using micropillar compression tests and crystal plasticity finite element (CPFE) modelling. Circular cross-section micropillars were fabricated from martensitic blocks within polycrystalline P91 steel using focused ion beam (FIB) and scanning electron microscopy (SEM) techniques. These micropillars, with various crystallographic orientations, were designed to activate different slip plane families in the body-centered cubic (BCC) structure. Compression tests were performed under both displacement-controlled and load-controlled conditions. Following compression, post-deformation electron backscatter diffraction (EBSD) analysis was conducted on the micropillar cross-sections to determine the grain distribution along their lengths. Slip system activation during compression was observed by analysing slip traces in the SEM images.

The micropillar compression tests were simulated using finite element (FE) modelling, incorporating phenomenological crystal plasticity. The geometry and crystallographic orientation of each micropillar, derived from SEM and EBSD data, were integrated into the simulations. The CPFE model was calibrated for each slip family based on the stress-strain curves from the micropillar tests, and the simulated slip traces were compared with experimental observations.

The analysis reveals that most micropillars follow Schmid's law, with non-Schmid effects having minimal influence on slip activation. Additionally, the yield stress and strain hardening behaviour of the micropillars are significantly influenced by the testing method. Across all series examined, the load-controlled tests generally exhibited lower strain hardening compared to the displacement-controlled tests. Finally, the critical resolved shear stress (CRSS) for each slip family was evaluated, and the accuracy of slip trace predictions-particularly regarding the angle of slip traces and the shape of the deformed micropillars for the {110}, {112}, and {123} slip plane families-was verified.

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